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(54) **RADIATION IMAGE CAPTURING APPARATUS AND METHOD OF DRIVING THE SAME**

(58) **Field of Classification Search**  
CPC ..... G01T 1/026; G01T 1/02  
See application file for complete search history.

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**H04N 5/33** (2006.01)

(52) **U.S. Cl.**

CPC ..... **H04N 5/378** (2013.01); **H04N 5/33** (2013.01)

(57) **ABSTRACT**

A radiation image capturing apparatus, comprising a sensor configured to monitor an irradiating dose of radiation, a switch configured output a sensor signal from the sensor, a readout unit configured to read out the sensor signal via a signal line, and a controlling unit, wherein the controlling unit performs first control of repeatedly performing, while the sensor is irradiated, a series of operations including a first operation of setting the switch to a conductive state and a second operation of setting the switch to a non-conductive state, second control of reading out the sensor signal in the first operation as a first signal and a potential of the signal line in the second operation as a second signal, and third control of calculating the irradiating dose of radiation based on the first signal and the second signal.

**20 Claims, 7 Drawing Sheets**

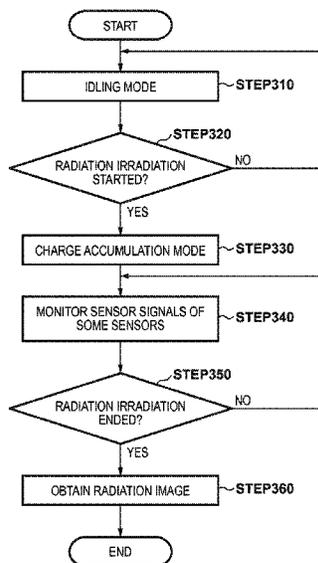
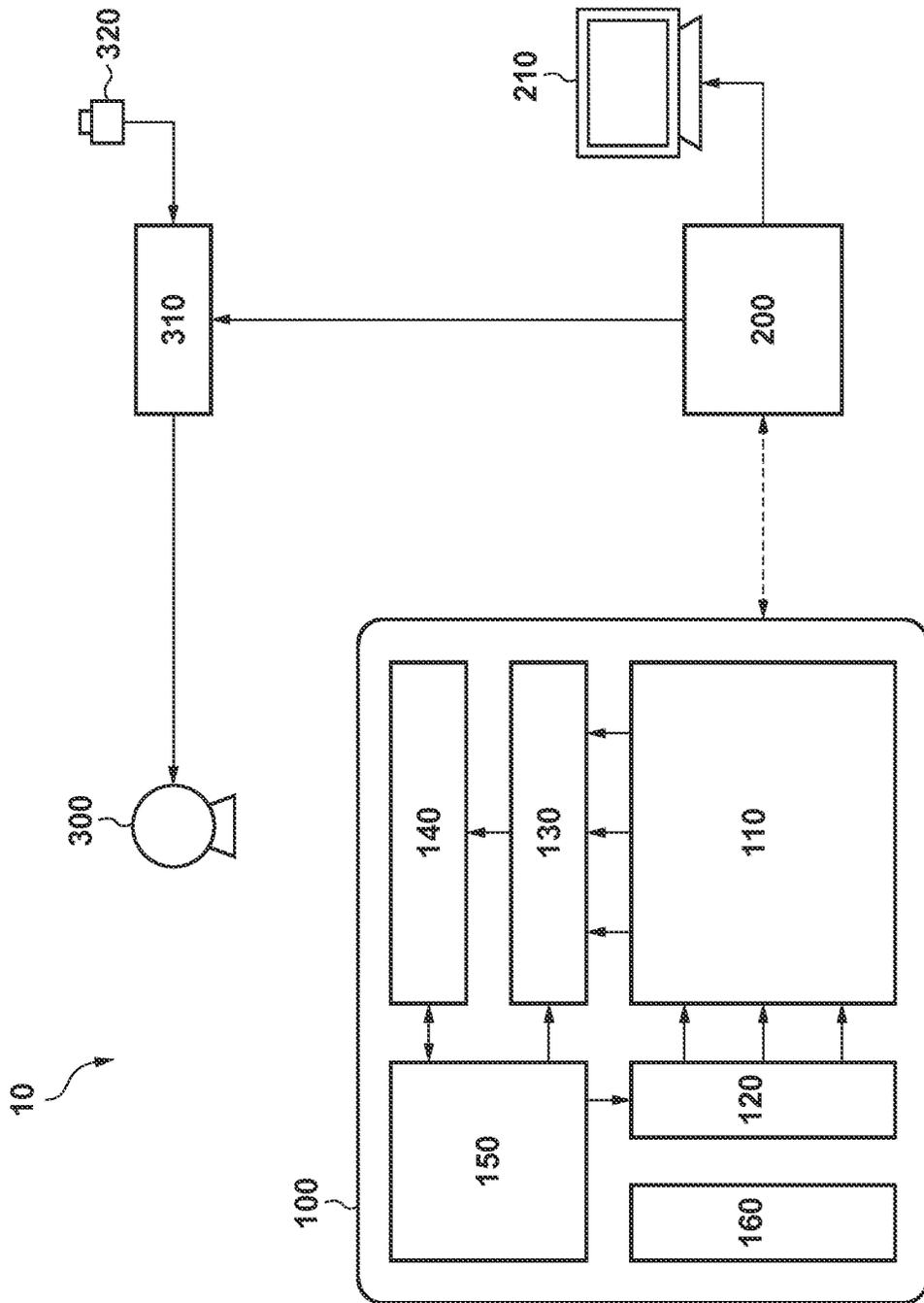


FIG. 1



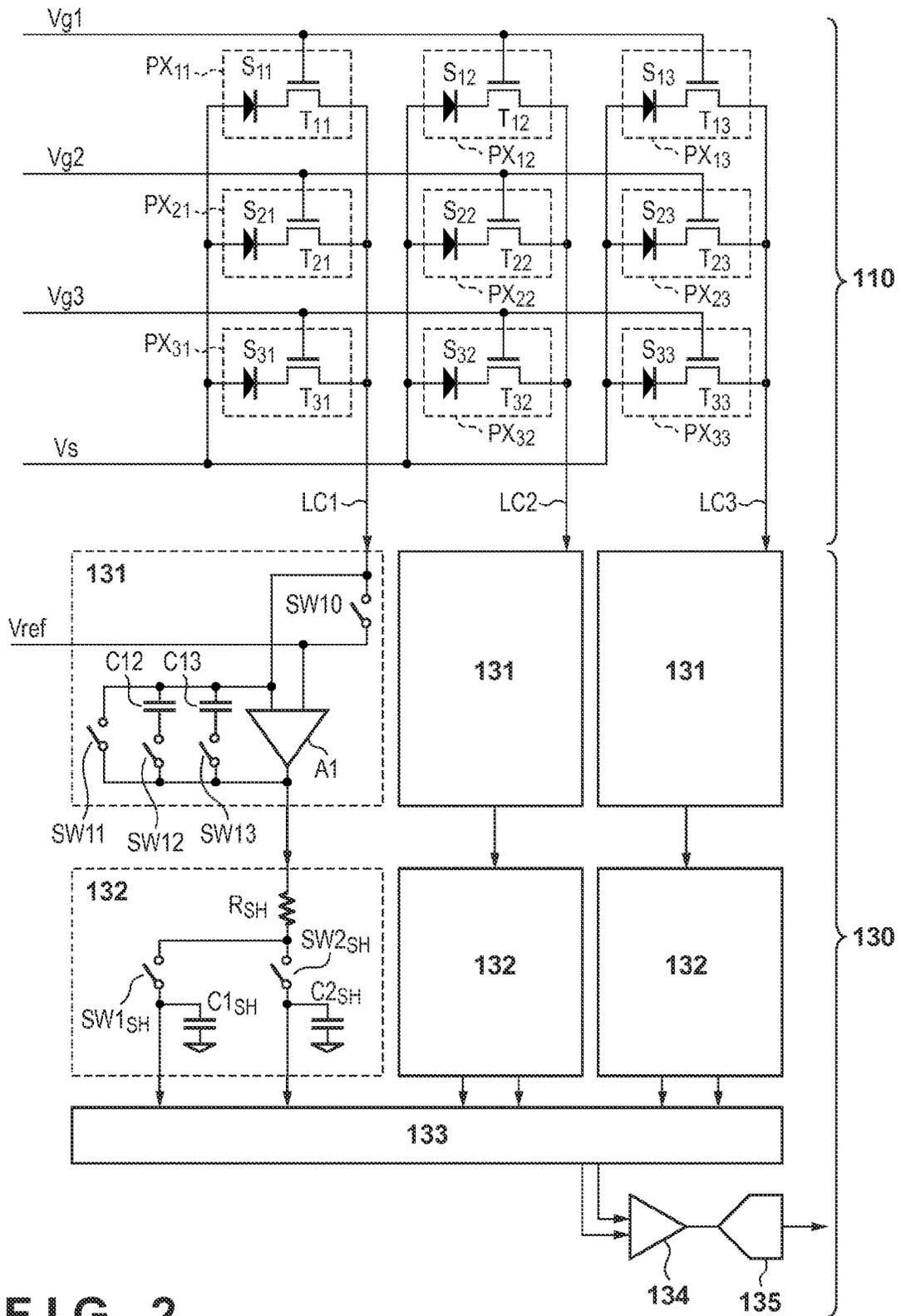


FIG. 2

FIG. 3

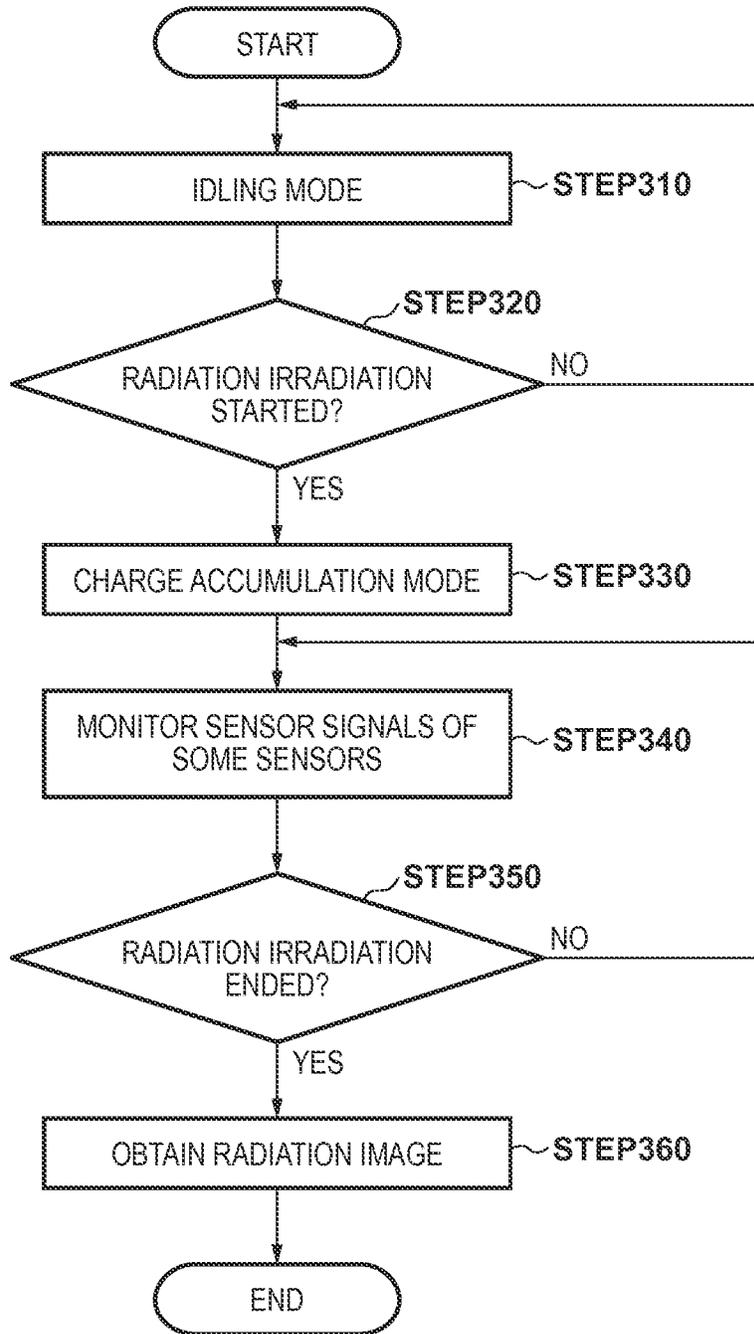
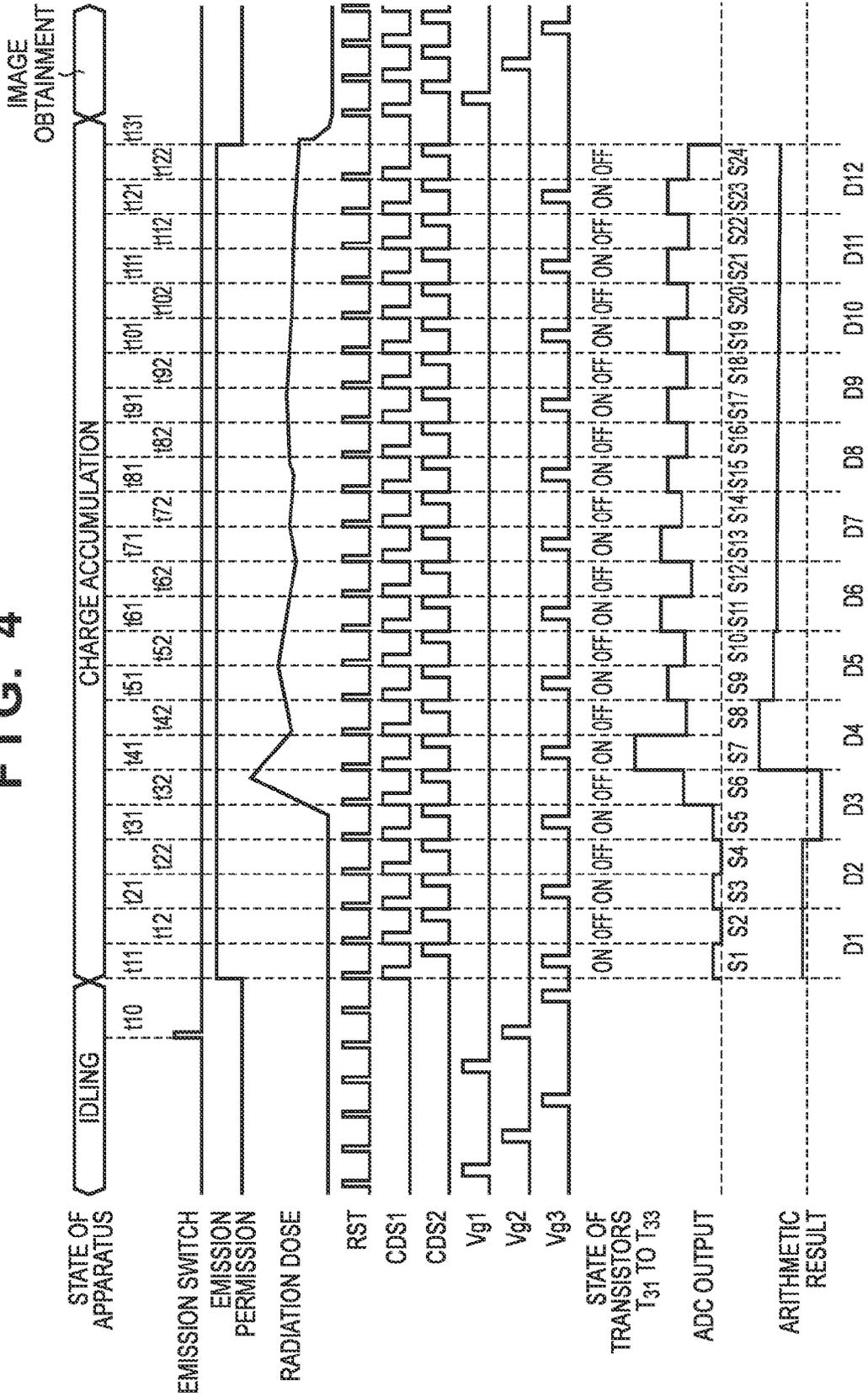


FIG. 4



**FIG. 5A**

TUBE VOLTAGE [kVp]	TUBE CURRENT [mA]	PARAMETER T [μsec]
70	50	500
70	50	510
70	200	800
110	50	1000
110	50	980
80	50	300
60	100	200

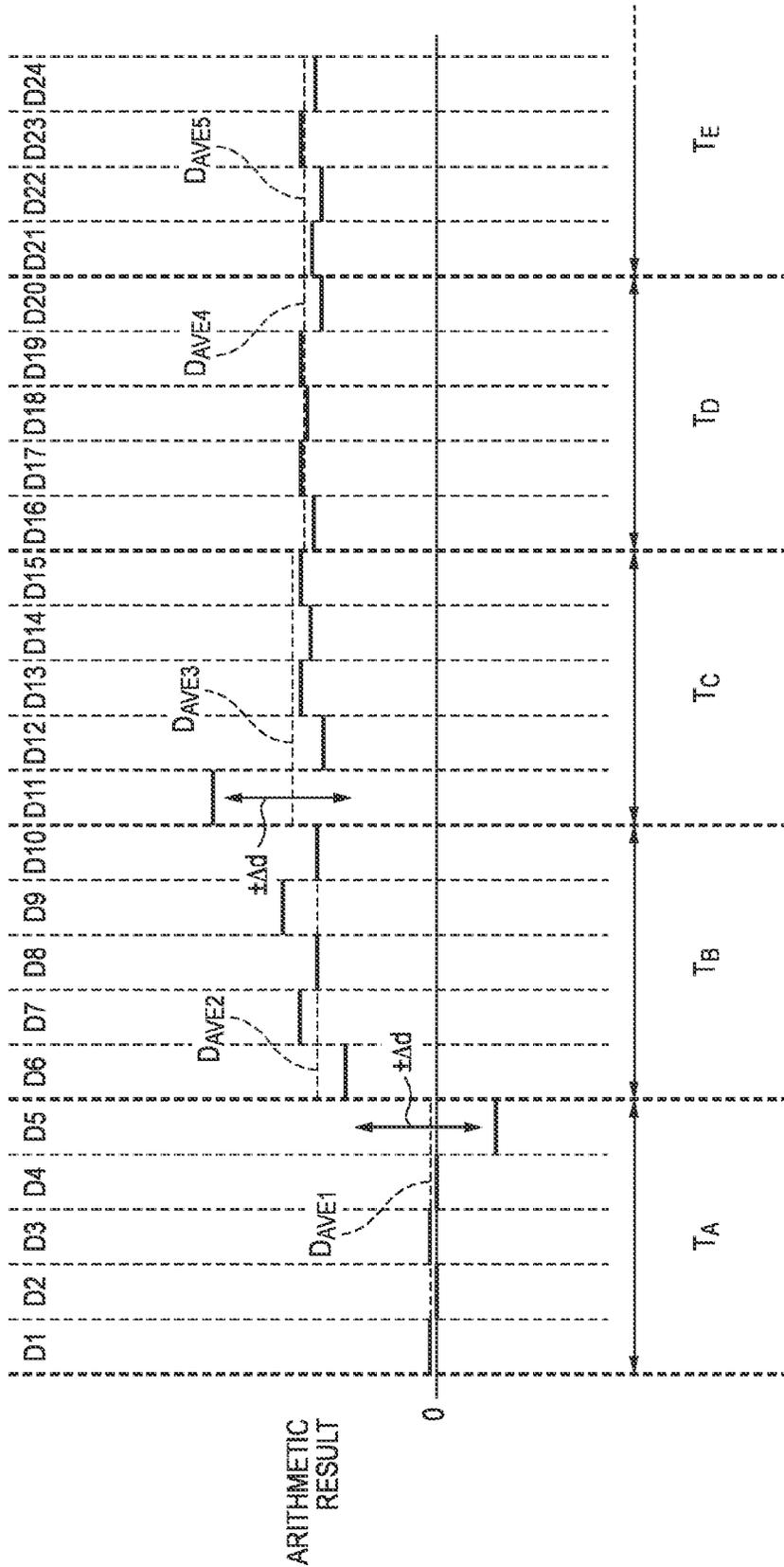
T<sub>MAX</sub> = 1000

**FIG. 5B**

TUBE VOLTAGE [kVp]	TUBE CURRENT [mA]	PARAMETER T [μsec]
70	50	500
80	100	1000
70	200	800
110	50	1000
80	100	400
70	50	300
60	100	200



FIG. 7



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# RADIATION IMAGE CAPTURING APPARATUS AND METHOD OF DRIVING THE SAME

## BACKGROUND OF THE INVENTION

### 1. Field of the Invention

The present invention relates to a radiation image capturing apparatus and a method of driving the same.

### 2. Description of the Related Art

Japanese Patent Laid-Open No. 2013-135390 has disclosed a radiation image capturing apparatus including a plurality of sensors configured to detect radiation and a readout unit configured to read out signals from the plurality of sensors. The plurality of sensors of the radiation image capturing apparatus include, in addition to an imaging sensor configured to perform radiation imaging, a monitor sensor configured to monitor an irradiating dose of radiation from a radiation source.

According to Japanese Patent Laid-Open No. 2013-135390, the signals are regularly read out from the monitor sensor during radiation irradiation and Auto Exposure Control (to be simply referred to as "AEC" hereinafter) of, for example, controlling the radiation source based on the signals is performed.

A control signal for reading out the signals from the sensors is supplied to the readout unit. For example, when reading out the signals from the monitor sensor, crosstalk may occur between a signal line which transmits the control signal and a signal line which transmits the signals from the monitor sensor, and a signal level from the monitor sensor may vary. The signal level from the monitor sensor may also vary by, for example, substrate noise caused by operating the readout unit. This may cause a decrease in AEC accuracy.

## SUMMARY OF THE INVENTION

The present invention provides a technique advantageous in increasing AEC accuracy.

One of the aspects of the present invention provides a radiation image capturing apparatus, comprising a sensor configured to monitor an irradiating dose of radiation from a radiation source, a switch configured to cause the sensor to output a sensor signal upon changing from a non-conductive state to a conductive state, a readout unit configured to read out the sensor signal from the sensor via the switch and a signal line, and a controlling unit configured to control the switch and the readout unit so as to perform first control of repeatedly performing, while radiation from the radiation source irradiates the sensor, a series of operations of a first operation of setting the switch to the conductive state and a second operation of setting the switch to the non-conductive state, second control of reading out, by the readout unit, the sensor signal from the sensor in the first operation as a first signal and reading out, by the readout unit, a potential of the signal line in the second operation as a second signal, and third control of calculating the irradiating dose of radiation based on the first signal and the second signal.

Further features of the present invention will become apparent from the following description of exemplary embodiments with reference to the attached drawings.

## BRIEF DESCRIPTION OF THE DRAWINGS

FIG. 1 is a block diagram for explaining an example of the system arrangement of a radiation image capturing apparatus;

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FIG. 2 is a diagram for explaining an example of the arrangement of an image capturing unit;

FIG. 3 is a flowchart for explaining an example of a method of driving the image capturing unit and AEC;

FIG. 4 is a timing chart for explaining the example of the method of driving the image capturing unit and AEC;

FIGS. 5A and 5B are tables for explaining an example of a parameter for AEC;

FIG. 6 is a timing chart for explaining an example of AEC; and

FIG. 7 is a timing chart for explaining an example of AEC.

## DESCRIPTION OF THE EMBODIMENTS

### 1. First Embodiment

The first embodiment will be described with reference to FIGS. 1 to 5B.

#### 1-1. System Arrangement Example of Radiation Image Capturing Apparatus

FIG. 1 is a block diagram for explaining an example of the system arrangement of a radiation image capturing apparatus 10 (may be referred to as a radiation inspection apparatus and to be simply referred to as an "apparatus 10" hereinafter). The apparatus 10 includes, for example, an image capturing unit 100, a computer 200, a displaying unit 210, a radiation source 300, a radiation controlling unit 310, and an emission switch 320.

The image capturing unit 100 includes, for example, a sensor array 110, a driving unit 120, a readout unit 130, a processing unit 140, a controlling unit 150, and a power supplying unit 160.

The sensor array 110 includes a plurality of sensors arrayed so as to form a plurality of rows and a plurality of columns. The sensors include photoelectric conversion elements such as PIN sensors, MIS sensors, and the like formed on a glass substrate by using amorphous silicon. A scintillator which converts radiation into light can be arranged on the sensor array 110. A so-called indirect conversion type arrangement in which radiation to each sensor is converted into light by the scintillator and the light is converted into an electrical signal by the photoelectric conversion element will be exemplified here. However, a so-called direct conversion type arrangement in which radiation is (directly) converted into an electrical signal may be adopted.

The driving unit 120 drives, for example, each sensor of the sensor array 110 based on a control signal from the controlling unit 150. The readout unit 130 reads out, based on the control signal from the controlling unit 150, a sensor signal (sometimes to be simply referred to as a "signal" hereinafter in this specification) from each sensor. The sensor signal corresponds to the dose of radiation that has entered each sensor and corresponds to, in this arrangement, the amount of charges accumulated in each sensor by photoelectric conversion. The processing unit 140 forms the image data of a radiation image based on the sensor signal read out from each sensor. The controlling unit 150 controls the driving unit 120 and the readout unit 130 by using the control signal. A dedicated circuit such as ASIC (Application Specific Integrated Circuit) may be used as the controlling unit 150. Alternatively, its function may be realized by a program or software using computer and the like. The power supplying unit 160 generates a plurality of voltages

based on an externally received power supply voltage and supplies, to each corresponding unit, the voltage for operating it properly.

The image capturing unit **100** and the computer **200** are connected to each other by a communication unit (not shown). The communication unit causes, for example, the image capturing unit **100** to receive a control signal corresponding to information required for imaging from the computer **200**. Image data formed by the processing unit **140** of the image capturing unit **100** is output to the computer **200** via the communication unit. The communication unit may be a wired communication unit such as a LAN cable or a wireless communication unit such as a wireless LAN.

The computer **200** controls the operation of the entire apparatus **10** by performing synchronous control of the respective units. A user can, for example, input a part to be an imaging target, an imaging condition, and other information required for imaging to the computer **200** by using a predetermined terminal. Based on the input information, the computer **200** exchanges control signals for performing radiation imaging with the image capturing unit **100** and causes, upon receiving image data obtained by the image capturing unit **100** in the radiation imaging, the displaying unit **210** to display the image data. The computer **200** can also inform the user of the state of the image capturing unit **100** by causing the displaying unit **210** to display the state.

The computer **200** outputs, in accordance with the state of the image capturing unit **100**, a control signal for restricting the start of radiation imaging to the radiation controlling unit **310**. In response to pressing the emission switch **320** by the user in a state in which radiation imaging can be started, the radiation controlling unit **310** drives the radiation source **300** and starts irradiating the image capturing unit **100** with radiation.

Note that the arrangement of the apparatus **10** is not limited to this example, but a part of it may be changed in accordance with a purpose, application, or the like. For example, some of the respective units may belong to other units or each unit may have an additional function different from the function that has been described in this example.

### 1-2. Arrangement Example of Image Capturing Unit

FIG. **2** is a diagram for explaining an example of the arrangement of portions of the sensor array **110** and the readout unit **130** out of the image capturing unit **100**. The sensor array **110** includes, for example, pixels PX, that is, PX<sub>11</sub> to PX<sub>33</sub> arrayed in three (rows)×three (columns). The respective pixels PX include sensors S, that is, S<sub>11</sub> to S<sub>33</sub>, and thin film transistors T, that is, T<sub>11</sub> to T<sub>33</sub> each serving as a switch connected to one terminal of each sensor S. The arrangement of three (rows)×three (columns) is exemplified for the sake of simplicity. However, the numbers of rows and columns are not limited to this example.

The gate of each transistor T is connected to, for example, a corresponding signal line out of signal lines Vg, that is, Vg1 to Vg3 arranged for the respective rows. Control signals are supplied to the gates via the signal lines Vg. For example, each transistor T changes to a conductive state when the control signal is at high level (H) and each transistor T changes to a non-conductive state when the control signal is at low level (L). By changing the transistors T to the conductive state, sensor signals of the sensors S are read out, by the readout unit **130**, via column signal lines LC, that is, LC1 to LC3 arranged for the respective columns of

the sensor array **110**. Note that a ground bias line Vs is connected to the other terminal of each sensor S.

The readout unit **130** includes column amplifiers **131**, sampling units **132**, a multiplexer **133**, a differential amplifier **134**, and an analog-to-digital conversion unit **135** (to be referred to as an “A/D conversion unit **135**” hereinafter).

The column amplifier **131** is arranged for each column of the sensor array **110** and includes, for example, an amplifier A1, switches SW10 to SW13, and feedback capacitors C12 and C13. One input terminal of each amplifier A1 is electrically connected to a reference potential Vref and connected to the column signal line LC via the switch SW10. The other input terminal of each amplifier A1 is connected to the column signal line LC. The potential of each column signal line LC is reset (becomes Vref) by setting the switch SW10 to the conductive state. The sensor signal is input to the other input terminal when the switch SW10 is in the non-conductive state.

For example, a feedback path including the switches SW11 to SW13 and the capacitors C12 and C13 is formed between the other input terminal and the output terminal of each amplifier A1. More specifically, the switch SW11 forms the first feedback path. The switch SW12 and the capacitor C12 are connected to each other in series and form the second feedback path. The switch SW13 and the capacitor C13 are connected to each other in series and form the third feedback path. The first to the third feedback paths are arranged in parallel to each other.

Each column amplifier **131** amplifies the sensor signal from each sensor S by setting the switch SW11 to the non-conductive state and setting at least one of the switches SW12 and SW13 to the conductive state. The signal amplification ratio of each column amplifier **131** changes when the switch SW12 is set to the conductive state, the switch SW13 is set to the conductive state, and when both the switches SW12 and SW13 are set to the conductive state, and can be changed in accordance with, for example, the imaging condition. Each column amplifiers **131** is initialized by setting the switch SW11 to the conductive state.

Each sampling unit **132** corresponds to the column amplifier **131** and samples a signal from the corresponding column amplifier **131**. Each sampling unit **132** includes, for example, a resistive element R<sub>SH</sub>, sampling switches SW1<sub>SH</sub> and SW2<sub>SH</sub>, and sampling capacitors C1<sub>SH</sub> and C2<sub>SH</sub>. For example, the output value of each column amplifier **131** when initializing the column amplifier **131** (when setting the switch SW11 to the conductive state) is sampled by setting the switch SW1<sub>SH</sub> to the conductive state and held in the capacitor C1<sub>SH</sub>. On the other hand, the sensor signal amplified by each column amplifier **131** is sampled by setting the switch SW2<sub>SH</sub> to the conductive state and held in the capacitor C2<sub>SH</sub>.

The resistive element R<sub>SH</sub> forms a low-pass filter together with the capacitor C1<sub>SH</sub> or C2<sub>SH</sub> when the switch SW1<sub>SH</sub> or SW2<sub>SH</sub> changes to the conductive state. This makes it possible to remove high-frequency noise such as spike noise. The resistive element R<sub>SH</sub> may be a variable resistor and may be changed in accordance with, for example, the imaging condition.

The multiplexer **133** selects any one of the sampling units **132** arranged for the respective columns, and outputs, to the differential amplifier **134**, signals held in the capacitors C1<sub>SH</sub> and C2<sub>SH</sub> of the selected sampling unit **132**. The differential amplifier **134** amplifies the difference between the signal held in the capacitor C1<sub>SH</sub> of the selected sampling unit **132** and the signal held in the capacitor C2<sub>SH</sub> of the selected sampling unit **132**. The offset component of each column

amplifier **131** is substantially removed by obtaining the difference between the signal held in the capacitor  $C1_{SH}$  and the signal held in the capacitor  $C2_{SH}$ .

Then, the signals from the differential amplifier **134** are analog-to-digital converted (A/D converted) by the A/D conversion unit **135**. The processing unit **140** can perform predetermined arithmetic processing and signal processing on the A/D converted signals. For example, in addition to forming the image data of the radiation image based on the A/D converted signals, the processing unit **140** performs arithmetic processing for performing AEC, the detail of which will be described later.

### 1-3. Example of Method of Driving Radiation Image Capturing Apparatus and AEC

FIG. **3** is a flowchart for explaining an example of a method of driving the apparatus **10**. In STEP**310**, the apparatus **10** is in an idling mode and waits while performing a predetermined initialization operation in preparation for the start of radiation imaging. Note that in this period, each unit not in use may be maintained in a low power consumption mode or a pause mode in which, for example, power supply is suppressed.

In STEP**320**, determination of whether to start radiation irradiation is made. The determination can be made based on, for example, whether the user has pressed the emission switch **320**. If radiation irradiation is started, the process advances to STEP**330**. If the irradiation is not started, the process returns to STEP**310**.

In STEP**330**, radiation irradiation is started and charge accumulation is performed in each sensor S of the sensor array **110**. The charges corresponding to the dose of irradiated radiation are accumulated in each sensor S.

In STEP**340**, signals are read out from some sensors S and sensor signals of the some sensors S are monitored.

In STEP**350**, it is determined, based on a result of monitoring in STEP**340**, whether radiation irradiation is ended. More specifically, the dose of radiation (prediction value) which irradiates each sensor S is calculated based on the result of monitoring and it is determined, based on the calculation result, whether radiation irradiation is ended. If radiation irradiation is ended, the process advances to STEP**360**. If the irradiation is not ended, the process returns to STEP**340**.

In STEP**360**, radiation irradiation is ended, the signal is read out from each sensor S, and the image data of the radiation image is obtained based on the read out sensor signal.

A concrete example of the above-described flowchart will be described below with reference to FIG. **4**.

FIG. **4** is a timing chart for explaining an example of the method of driving the apparatus **10**. The abscissa of FIG. **4** represents the time axis. The ordinate of FIG. **4** represents the state of the apparatus **10**, the state of the emission switch **320**, emission permission/nonpermission, radiation dose (irradiating dose of radiation), various types of control signals, the state of the transistors  $T_{31}$  to  $T_{33}$  on the third row, the output of the A/D conversion unit **135**, and a result of arithmetic processing by the processing unit **140**.

A control signal RST is a reset signal for initializing each column amplifier **131**, and supplied to the switches SW**10** and SW**11**. A control signal CDS**1** is a control signal for sampling the output value of each column amplifier **131** when initializing the column amplifier **131**, and supplied to the switch SW**1<sub>SH</sub>**. A control signal CDS**2** is a control signal for sampling the sensor signal amplified by each column

amplifier **131**, and supplied to the switch SW**1<sub>SH</sub>**. Each of the signals Vg**1** to Vg**3** indicates a signal level at which each of the signal lines Vg**1** to Vg**3** is transmitted, that is, the potential of each of the signal lines Vg**1** to Vg**3**, and is supplied to the gate of each transistor T on the corresponding row.

In a period before starting radiation irradiation when the apparatus **10** is in the idling mode, the signals Vg**1** to Vg**3** are sequentially set to H while setting the control signal RST to H periodically. By doing so, each sensor of the sensor array **110** is initialized for each row while initializing each column amplifiers **131** and the potential of each column signal line LC, and the apparatus **10** waits in preparation for the start of radiation imaging. Note that in this period, each unit not in use may be maintained in the low power consumption mode or the pause mode in which, for example, power supply is suppressed.

In response to pressing the emission switch **320** under the idling mode (at time t**10** of FIG. **4**), the aforementioned initialization operation in the image capturing unit **100** is ended, and the computer **200** notifies the radiation controlling unit **310** of emission permission by setting an emission permission signal to H. Then, radiation irradiation is started by the radiation source **300**, the apparatus **10** changes to a charge accumulation mode, and the charges corresponding to the dose of irradiated radiation are accumulated in each sensor S of the sensor array **110**. At this time, the computer **200** may control the image capturing unit **100** by a predetermined control signal in response to pressing the emission switch **320**. However, the image capturing unit **100** itself may detect the start of radiation irradiation by a predetermined detecting unit.

At times t**11** to t**131** in the charge accumulation mode, the signal CDS**1** is set to H together with each pulse of the signal RST while setting the signal RST to H periodically, and then the signal CDS**2** is set to H. In this example, the signal Vg**3** is set to H in the respective periods between the pulse of the signal CDS**1** and the pulse of the signal CDS**2** at times t**11** and t**12**, t**21** and t**22**, . . . , t**211** and t**122**. On the other hand, the signal Vg**3** is maintained at L in the respective periods of times t**12** and t**21**, t**22** and t**31**, . . . , t**122** and t**131**.

For example, at times t**11** and t**12**, first, the signals RST and CDS**1** are set to H, and the output value of each column amplifier **131** when initializing the column amplifier **131** is sampled. Next, the signal Vg**3** is set to H and the transistors  $T_{31}$  to  $T_{33}$  on the third row are set to the conductive state. Then, the signal CDS**2** is set to H and the sensor signal amplified by each column amplifier **131** is sampled. An output S**1** indicates the output value (for the sake of simplicity, assume that it is the average value on the first to the third columns) of the A/D conversion unit **135** which has received the above-described sampling result.

Next, at times t**12** and t**21**, first, the signals RST and CDS**1** are set to H, and the output value of each column amplifier **131** when initializing the column amplifier **131** is sampled. Then, the signal CDS**2** is set to H and the sensor signal amplified by each column amplifier **131** is sampled while maintaining the signal Vg**3** at L (maintaining the transistors  $T_{31}$  to  $T_{33}$  in the non-conductive state). An output S**2** indicates the output value (for the sake of simplicity, assume that it is the average value on the first to the third columns) of the A/D conversion unit **135** which has received the above-described sampling result. An arithmetic result D**1** is obtained from arithmetic processing by the processing unit **140**, and indicates a signal level based on the difference between the output S**1** and the output S**2**.

A series of the above-described operations at times **t11** to **t21** is performed repeatedly in the same manner at times **t21** to **t131**. Outputs **S3**, **S5**, . . . , **S23** indicate the output values of the A/D conversion unit **135** corresponding to the sampling result when performing the above-described sampling while setting the transistors  $T_{31}$  to  $T_{33}$  to the conductive state. On the other hand, outputs **S4**, **S6**, . . . , **S24** indicate the output values of the A/D conversion unit **135** corresponding to the sampling result when performing the above-described sampling while maintaining the transistors  $T_{31}$  to  $T_{33}$  in the non-conductive state. Each of arithmetic results **D2**, **D3**, . . . , **D12** is obtained from arithmetic processing by the processing unit **140**, and indicates a signal level based on the difference between the outputs **S3**, **S5**, . . . , **S23** and the outputs **S4**, **S6**, . . . , **S24**.

That is, when setting an integer of  $k=1$  to  $n$  (here,  $n=12$ ),

$$Dk=S(2k-1)-S(2k) \text{ is given.}$$

The controlling unit **150** receives arithmetic results  $Dk$  from the processing unit **140** and performs AEC (Auto Exposure Control) based on the arithmetic results  $Dk$ . Specifically, for example, the controlling unit **150** calculates, based on the arithmetic results  $Dk$ , the dose of radiation which irradiates each sensor **S** and controls the radiation source **300** based on the calculation result. More specifically, the controlling unit **150** notifies the computer **200** of the radiation dose and any other state by a predetermined control signal, and the radiation controlling unit **310** controls the radiation source **300** based on the control signal from the computer **200**. For example, the controlling unit **150** can control at least one of the irradiation dose, the irradiation intensity, and the irradiation time of radiation, and sets the emission permission signal to **L** to terminate radiation irradiation when the radiation dose satisfies a predetermined condition. In this example, the emission permission signal is set to **L** at time **t131** to terminate radiation irradiation.

The arrangement in which the controlling unit **150** controls the radiation source **300** indirectly by using the computer **200** and the radiation controlling unit **310** is exemplified. However, an arrangement in which the controlling unit **150** controls the radiation source **300** directly may be adopted.

Note that when reading out the signal from each sensor **S**, a signal level based on the above-described sampling result and another sensor signal may vary due to, for example, a parasitic capacitance between each column signal line **LC** and each signal line which supplies the control signal to the readout unit **130**. The signal level may also vary due to, for example, substrate noise caused by operating the readout unit **130**. During radiation irradiation, in each pixel **PX** where the transistor **T** is in the non-conductive state, the potential of the sensor **S** increases and the voltage is transmitted to the column signal line **LC** via the parasitic capacitance between the column signal line **LC** and the pixel. This may also vary the signal level. These variations are also referred to as crosstalk noise. Therefore, in this embodiment, the difference between the sampling result (outputs **S1**, **S3**, . . . , **S23**) when the transistors  $T_{31}$  to  $T_{33}$  are in the conductive state and the sampling result (outputs **S2**, **S4**, . . . , **S24**) when the transistors  $T_{31}$  to  $T_{33}$  are in the non-conductive state is obtained. As a result, crosstalk noise is canceled, that is, crosstalk noise is substantially removed from the sampling result (outputs **S1**, **S3**, . . . , **S23**) when the transistors  $T_{31}$  to  $T_{33}$  are in the conductive state. This embodiment is advantageous in increasing AEC accuracy because AEC is performed based on the arithmetic results  $Dk$  from which crosstalk noise is removed substantially.

Then, the apparatus **10** changes to an image obtaining mode in which the sensor signal is read out from each sensor **S** of the sensor array **110** and the image data of the radiation image is obtained based on the read out sensor signal. According to this example, the signals are read out periodically at times **t11** to **t131** in the sensors  $S_{31}$  to  $S_{33}$  on the third row, and charge accumulation times in the sensors  $S_{31}$  to  $S_{33}$  are different from those in the sensors  $S_{11}$  to  $S_{13}$  on the first row and the sensors  $S_{21}$  to  $S_{23}$  on the second row. Therefore, the sensor signals from the sensors  $S_{31}$  to  $S_{33}$  on the third row can be corrected based on the ratio of these charge accumulation times.

#### 1-4. Modification of AEC

In the aforementioned example of FIG. 4, after a predetermined delay since the emission permission signal has changed to **H**, the radiation dose increases before time **t32** and between times **t32** and **t41**, it is not stable and formed into a spike shape in a period shorter than a period required for a onetime signal readout operation. In this case, since the arithmetic result **D3** has a negative value, AEC may be performed based on the arithmetic results after **D4**. For example, if the total sum of the arithmetic results **D4** to **D12** becomes larger than a predetermined value, radiation irradiation can be ended.

Note that a delay time of radiation irradiation and the spike-shaped radiation dose immediately after the start of radiation irradiation described above result from, for example, a time required to generate a high voltage required for radiation irradiation, a potential variation of a power supply voltage supplied to the apparatus **10**, and the characteristic of a tube for generating radiation. Therefore, the arithmetic result **D1** or the like from the time when the emission permission signal has changed to **H** at time **t11** until a predetermined time has elapsed may not be used for AEC.

This can be performed by, for example, evaluating the apparatus **10**, storing a reference table for specifying the above-described predetermined time or a parameter corresponding to the above-described predetermined time in a predetermined memory (not shown) in the advance, and then referring to the reference table when performing radiation imaging.

A parameter **T** is set as, for example, a period from time **t11** at which the emission permission signal changes to **H** (that is, time at which the apparatus **10** changes from the idling mode to the charge accumulation mode). The parameter **T** may be set, for example, based on the imaging condition input by the user before starting radiation imaging while referring to the above-described reference table. However, the parameter **T** may be set directly by the user or may be a fixed value.

FIG. 5A shows, for each condition, a reference table which defines the parameter **T** obtained by the evaluation of the apparatus **10**. The parameter **T** for each condition is set as, for example, a period from time **t11** until the output value of the A/D conversion unit **135** becomes larger than the predetermined value. For example, the maximum value  $T_{MAX}$  out of the obtained parameters **T** described above may usually be used as the fixed-value parameter **T**. Using the maximum-value parameter  $T_{MAX}$  makes it possible to perform AEC only by using the appropriate arithmetic result out of some arithmetic results  $Dk$ .

FIG. 5B shows, for each condition, a reference table which defines the parameter **T** obtained by radiation imaging that has performed under some imaging conditions. The tube

for generating radiation and the other respective units which constitute the apparatus **10** may deteriorate each time radiation imaging is performed. Therefore, the above-described reference table may be updated based on the output **S1** or the like obtained by each radiation imaging.

The mode in which AEC is performed by using the arithmetic results **Dk** from the time when the emission permission signal has changed to **H** at time **t11** until a time based on the parameter **T** has elapsed is exemplified here. However, the processing unit **140** may be controlled to start the arithmetic operation after the time has elapsed.

The reference table is stored in a predetermined database for each IP address. The parameter **T** corresponding to the imaging condition may be set as needed by referring to the reference table corresponding to the IP address of the apparatus **10**.

### 1-5. Others

In this embodiment, the mode in which AEC is performed based on the signals from the sensors **S<sub>31</sub>** to **S<sub>33</sub>** on the third row in the charge accumulation mode is exemplified. However, the example of AEC is not limited to this mode. That is, AEC can be performed based on the signals from at least some sensors **S** of the sensor array **110**. The signals from the sensors **S<sub>11</sub>** to **S<sub>13</sub>** on the first row, the sensors **S<sub>21</sub>** to **S<sub>23</sub>** on the second row, and/or the sensors **S<sub>31</sub>** to **S<sub>33</sub>** on the third row may be used for AEC.

The arrangement in which AEC is performed based on the signal from each sensor **S** which forms the corresponding pixel **PX** is exemplified in this embodiment. However, an arrangement in which the sensor array **110** further includes a sensor different from the sensor **S** which forms each pixel **PX** and designed specifically for monitoring the radiation dose may be adopted.

### 2. Second Embodiment

The second embodiment will be described with reference to FIG. 6. The main difference between this embodiment and the aforementioned first embodiment is that an offset component caused by a difference in the state of transistors **T<sub>31</sub>** to **T<sub>33</sub>** is further removed from arithmetic results **Dk**. More specifically, an output value of an A/D conversion unit **135** when the transistors **T<sub>31</sub>** to **T<sub>33</sub>** are in a conductive state and an output value of the A/D conversion unit **135** when the transistors **T<sub>31</sub>** to **T<sub>33</sub>** are in a non-conductive state are obtained before setting an emission permission signal to **H** (before an apparatus **10** changes to a charge accumulation mode). Then, the offset component caused by the difference in the state of the transistors **T<sub>31</sub>** to **T<sub>33</sub>** is calculated based on these output values.

FIG. 6 shows, as in FIG. 4, a part of a timing chart (more specifically, emission permission/nonpermission, radiation dose, the state of the transistors **T<sub>31</sub>** to **T<sub>33</sub>**, the output of the A/D conversion unit **135**, and a result of arithmetic processing by a processing unit **140**) according to this embodiment. As shown in FIG. 6, in a period **TO** before setting the emission permission signal to **H** (before the apparatus **10** changes to the charge accumulation mode), outputs **N1** and **N2** of the A/D conversion unit **135** when the transistors **T<sub>31</sub>** to **T<sub>33</sub>** are in the conductive state and the non-conductive state are obtained. Then, arithmetic results **Dk'** obtained by subtracting the offset component serving as the difference between the output **N1** and the output **N2** from the aforementioned arithmetic results **Dk** are obtained.

That is, the arithmetic results **Dk'** are given by using an integer of **k=1** to **n** (here, **n=12**):

$$Dk' = Dk - (N1 - N2) = \{S(2k-1) - S(2k)\} - (N1 - N2)$$

AEC is performed based on the arithmetic results **Dk'**.

This embodiment is advantageous in further increasing AEC accuracy because the offset component caused by the difference in the state of the transistors **T<sub>31</sub>** to **T<sub>33</sub>** is further removed from the aforementioned arithmetic results **Dk** from which crosstalk noise is removed substantially. The mode in which the outputs **N1** and **N2** are obtained one by one is exemplified here. However, the present invention is not limited to this mode, but the average value of the offset component (**N1-N2**) may be obtained by obtaining the outputs **N1** and **N2** twice or more.

### 3. Third Embodiment

The third embodiment will be described with reference to FIG. 7. The main difference between this embodiment and the aforementioned first embodiment is that AEC is performed by using the average value of arithmetic results **Dk** for each predetermined section. According to this embodiment, AEC accuracy can be increased even if some arithmetic results **Dk** become singular values by sudden high-frequency noise.

If, for example, the difference between a given arithmetic result **Dk** and an average value **D<sub>AVE</sub>** in a section corresponding to it is larger than a predetermined reference, the arithmetic result **Dk** may be replaced by the average value **D<sub>AVE</sub>**. More specifically, as illustrated in FIG. 7, an average value **D<sub>AVE</sub>** of five arithmetic results is calculated and if, for example, the difference between an average value **D<sub>AVE1</sub>** of arithmetic results **D1** to **D5** and the arithmetic result **D5** is larger than a reference  $\pm\Delta d$ , AEC is performed by using the average value **D<sub>AVE1</sub>** instead of the arithmetic result **D5**. Furthermore, if, for example, the difference between an average value **D<sub>AVE3</sub>** of arithmetic results **D11** to **D15** and the arithmetic result **D11** is larger than the reference  $\pm\Delta d$ , AEC is performed by using the average value **D<sub>AVE3</sub>** instead of the arithmetic result **D11**.

In this example, the mode in which if the difference between the given arithmetic result **Dk** and the average value **D<sub>AVE</sub>** in the section corresponding to it is larger than the predetermined reference, AEC is performed by using the average value **D<sub>AVE</sub>** instead of the arithmetic result **Dk** is exemplified. However, the present invention is not limited to this mode. For example, if the difference between adjacent arithmetic results **Dk** is larger than a predetermined reference, AEC may be performed by using the average values **D<sub>AVE</sub>**. Further, in this example, the mode in which the arithmetic result **Dk** is replaced by the average values **D<sub>AVE</sub>** is exemplified. However, AEC can be performed without using the arithmetic result **Dk** and another processing may be performed on the arithmetic result **Dk**. AEC may be performed by, for example, using, instead of the arithmetic result **Dk**, the average value of arithmetic results **D(k-1)** and **D(k+1)** before and after the arithmetic result **Dk**. Alternatively, AEC may be performed based on a predetermined statistical result of the arithmetic result **Dk**.

### 4. Others

The several preferred embodiments have been exemplified above. However, the present invention is not limited to these embodiments. The present invention may change some

of the respective modes or combine the respective characteristics of the respective embodiments in accordance with an application or the like.

Embodiment(s) of the present invention can also be realized by a computer of a system or apparatus that reads out and executes computer executable instructions (e.g., one or more programs) recorded on a storage medium (which may also be referred to more fully as a 'non-transitory computer-readable storage medium') to perform the functions of one or more of the above-described embodiment(s) and/or that includes one or more circuits (e.g., application specific integrated circuit (ASIC)) for performing the functions of one or more of the above-described embodiment(s), and by a method performed by the computer of the system or apparatus by, for example, reading out and executing the computer executable instructions from the storage medium to perform the functions of one or more of the above-described embodiment(s) and/or controlling the one or more circuits to perform the functions of one or more of the above-described embodiment(s). The computer may comprise one or more processors (e.g., central processing unit (CPU), micro processing unit (MPU)) and may include a network of separate computers or separate processors to read out and execute the computer executable instructions. The computer executable instructions may be provided to the computer, for example, from a network or the storage medium. The storage medium may include, for example, one or more of a hard disk, a random-access memory (RAM), a read only memory (ROM), a storage of distributed computing systems, an optical disk (such as a compact disc (CD), digital versatile disc (DVD), or Blu-ray Disc (BD)<sup>TM</sup>), a flash memory device, a memory card, and the like.

While the present invention has been described with reference to exemplary embodiments, it is to be understood that the invention is not limited to the disclosed exemplary embodiments. The scope of the following claims is to be accorded the broadest interpretation so as to encompass all such modifications and equivalent structures and functions.

This application claims the benefit of Japanese Patent Application No. 2014-148161, filed Jul. 18, 2014, which is hereby incorporated by reference herein in its entirety.

What is claimed is:

1. A radiation image capturing apparatus, comprising:
  - a sensor configured to monitor an irradiating dose of radiation from a radiation source;
  - a switch configured to cause said sensor to output a sensor signal upon changing from a non-conductive state to a conductive state;
  - a readout unit configured to read out the sensor signal from said sensor via said switch and a signal line; and
  - a controlling unit configured to control the switch and the readout unit so as to perform first control of repeatedly performing, while radiation from the radiation source irradiates said sensor, a series of operations including a first operation of setting said switch to the conductive state and a second operation of setting said switch to the non-conductive state,
  - second control of reading out, by said readout unit, the sensor signal from said sensor in the first operation as a first signal and reading out, by said readout unit, a potential of the signal line in the second operation as a second signal, and
  - third control of calculating the irradiating dose of radiation based on the first signal and the second signal.
2. The apparatus according to claim 1, wherein in the third control, said controlling unit outputs a control signal for

controlling the radiation source and at least one of the irradiation dose, an irradiation intensity, and an irradiation time of radiation.

3. The apparatus according to claim 1, wherein for each of the series of the operations performed repeatedly, said controlling unit calculates a difference between the first signal obtained in the first operation and the second signal obtained in the second operation, and performs the third control based on the difference if the difference satisfies a predetermined condition.

4. The apparatus according to claim 1, wherein said controlling unit calculates an average value of a difference between the first signal obtained by the first operation and the second signal obtained by the second operation for the series of operations performed not less than twice, and performs the third control based on the average value.

5. The apparatus according to claim 1, wherein for each of the series of the operations performed repeatedly, said controlling unit performs the third control based on a difference between the first signal obtained by the first operation and the second signal obtained by the second operation and if the difference does not satisfy a predetermined condition, said controlling unit performs the third control based on an average value of differences between the first signals obtained by the first operations and the second signals obtained by the second operations for the series of operations performed not less than twice.

6. The apparatus according to claim 1, wherein said controlling unit performs fourth control of setting each switch to the conductive state and initializing each sensor before radiation irradiation starts, and

said controlling unit

performs the first control, the second control, and the third control after a predetermined time elapses since the fourth control has ended, or

performs the first control and the second control since the fourth control has ended and performs, after the predetermined time has elapsed since the fourth control had ended, the third control on the first control and the second control that have been performed after the predetermined time had elapsed.

7. The apparatus according to claim 6, further comprising a detecting unit configured to detect that the radiation source has started radiation irradiation,

wherein said controlling unit terminates the fourth control based on detection by said detecting unit.

8. The apparatus according to claim 6, further comprising a memory configured to hold a reference table for specifying the predetermined time,

wherein said controlling unit sets, while referring to the reference table, the predetermined time based on an imaging condition set by a user.

9. The apparatus according to claim 1, further comprising a plurality of pixels configured to obtain image data corresponding to radiation,

wherein at least one of the plurality of pixels includes said sensor and said switch.

10. A method of driving a radiation image capturing apparatus,

the radiation image capturing apparatus including a sensor configured to monitor an irradiating dose of radiation from a radiation source,

a switch configured to cause the sensor to output a sensor signal upon changing from a non-conductive state to a conductive state, and

a readout unit configured to read out the sensor signal from the sensor via the switch and a signal line,

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the method comprising steps of:  
 repeatedly performing, while radiation from the radiation source irradiates the sensor, a series of operations including a first operation of setting the switch to the conductive state and a second operation of setting the switch to the non-conductive state;  
 reading out, by the readout unit, the sensor signal from the sensor in the first operation as a first signal and reading out, by the readout unit, a potential of the signal line in the second operation as a second signal; and  
 calculating the irradiating dose of radiation based on the first signal and the second signal.

**11.** A radiation image capturing apparatus, comprising:  
 a sensor configured to monitor an irradiating dose of radiation from a radiation source;  
 a switch for outputting a signal from said sensor;  
 a controlling unit configured to control the switch so as to perform, while radiation from the radiation source irradiates said sensor, a first operation of switching said switch to a conductive state and a second operation of switching said switch to a non-conductive state; and  
 a calculation unit configured to calculate the irradiating dose of radiation based on a first signal obtained corresponding to the first operation and a second signal obtained corresponding to the second operation.

**12.** The apparatus according to claim **11**, wherein said controlling unit outputs a control signal for controlling the radiation source and at least one of the irradiation dose, an irradiation intensity, and an irradiation time of radiation.

**13.** The apparatus according to claim **11**, wherein said controlling unit, while the radiation from the radiation source irradiates said sensor, repeatedly performs a series of operations including the first operation and the second operation, and  
 said calculation unit calculates, for each of the series of the operations performed repeatedly, the irradiating dose of radiation based on a difference between the first signal and the second signal.

**14.** The apparatus according to claim **11**, wherein said controlling unit, while the radiation from the radiation source irradiates said sensor, repeatedly performs a series of operations including the first operation and the second operation, and  
 said calculation unit calculates the irradiating dose of radiation based on an average value of a difference between the first signal and the second signal for the series of operations performed not less than twice.

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**15.** The apparatus according to claim **11**, wherein said controlling unit, while the radiation from the radiation source irradiates said sensor, repeatedly performs a series of operations including the first operation and the second operation, and  
 said calculation unit calculates, for each of the series of the operations performed repeatedly, the irradiating dose of radiation based on a difference between the first signal and the second signal and if the difference does not satisfy a predetermined condition, said calculation unit calculates the irradiating dose of radiation based on an average value of differences between the first signal and the second signal for the series of operations performed not less than twice.

**16.** The apparatus according to claim **11**, wherein said controlling unit performs initializing each sensor, before radiation irradiation starts, by setting each switch to the conductive state, and  
 said controlling unit performs the first operation and the second operation after a predetermined time elapses since the initializing has ended.

**17.** The apparatus according to claim **16**, further comprising a detecting unit configured to detect that the radiation source has started radiation irradiation,  
 wherein said controlling unit terminates the initializing based on detection by said detecting unit.

**18.** The apparatus according to claim **16**, further comprising a memory configured to hold a reference table for specifying the predetermined time,  
 wherein said controlling unit sets, while referring to the reference table, the predetermined time based on an imaging condition set by a user.

**19.** The apparatus according to claim **11**, further comprising a plurality of pixels configured to obtain image data corresponding to radiation,  
 wherein at least one of the plurality of pixels includes said sensor and said switch.

**20.** A method of driving a radiation image capturing apparatus, the radiation image capturing apparatus including a sensor configured to monitor an irradiating dose of radiation from a radiation source, and a switch for outputting a signal from the sensor, the method comprising steps of:  
 performing, while radiation from the radiation source irradiates the sensor, a first operation of switching the switch to a conductive state and a second operation of switching the switch to a non-conductive state; and  
 calculating the irradiating dose of radiation based on a first signal obtained corresponding to the first operation and a second signal obtained corresponding to the second operation.

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